NWC Technical Memorandum 3667

NASA CR-
160359

# AIRBORNE MEASUREMENTS OF CLOUD FORMING NUCLEI AND AEROSOL PARTICLES AT KENNEDY SPACE CENTER, FLORIDA

by


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December 1978

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## ABSTRACT

Results of airborne measurements of the sizes and concentrations of aerosol particles, ice nuclei, and cloud condensation nuclei that were taken at Kennedy Space Center, Florida are presented along with a detailed description of the instrumentation and measuring capabilities of the University of Washington airborne measuring facility (Douglas B-23). Airborne measurements made at Ft. Collins, Colorado and Little Rock, Arkansas during the ferry of the B-23 are presented.

The particle concentrations differed significantly between the clean air over Ft. Collins and the hazy air over Little Rock and Kennedy Space Center. The concentrations of cloud condensation nuclei over Kennedy Space Center were typical of polluted eastern seaboard air.

Three different instruments were used to measure ice nuclei: one used filters to collect the particles, and the others used optical and acoustical methods to detect ice crystals grown in portable cloud chambers. A comparison of the ice nucleus counts, which are in good agreement, is presented.

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## INTRODUCTION

Airborne measurements of ice nuclei (IN), cloud condensation nuclei (CCN), liquid and solid aerosol particles, and cloud volumes were made in stabilized ground clouds (SGCs) produced by Titan III launches at Kennedy Space Center (KSC) on 20 August and 5 September 1977.[1] The IN measurements, which were the focus of the flights, were not conclusive because counts from the portable counters and those using filters were inconsistent. It was recommended that laboratory studies of the various portable counters and filters be conducted to prepare them to monitor the SGC from the Titan III launch at KSC in March 1978.[2] The results of the laboratory investigations are reported by Hindman and others.[3]

The primary emphasis of the airborne measurements reported here was to study the ice nucleating properties of the effluents from the Titan III solid rocket motors. We planned to measure the structure of the SGC produced by the launch and the aerosol size distributions and CCN in the effluents. The Titan III launch was plagued by repeated postponements of the scheduled 13 March launch. The measurement aircraft (University of Washington) had other contractual obligations and had to return to Seattle before the launch finally took place on 25 March (due to malfunction, the rocket and payload were destroyed 8 minutes after blastoff). Therefore, the measurements reported here were obtained in air unaffected by rocket effluents during project flights in the vicinity of KSC. Data obtained during ferry flights from Ft. Collins, Colorado to Patrick AFB, Florida are presented for comparison purposes. The measurements obtained at KSC will be useful for comparisons with measurements from future flights at KSC.

## AIRBORNE MEASUREMENT FACILITY

The University of Washington Douglas B-23 is ideal for aerosol and cloud physics research and has been used in a wide variety of atmospheric research projects since 1970. It is a heavy (12,000 kg), twin-engine plane and can carry a crew of seven and more than 1,000 kg of equipment. It is an all-weather plane (equipped for instrument operations, all leading edges and propellers de-iced), has a service ceiling of 8,000 m, and has excellent maneuverability at all altitudes. At speeds between 35 and 85 m $s^{-1}$, it provides a stable sampling platform (normal sampling

speed 60 m $s^{-1}$), and its low cruising speed minimizes problems associated with small-particle sampling. The specialized instrumentation is described in the following section.

## DATA SYSTEM AND BASIC PARAMETERS

One of the most important characteristics of the B-24 research system is that, despite its extent and complexity, an adequate crew can be carried aboard to ensure its reliable operation. Moreover, the crew is provided with sufficient real-time data so that project goals can be adjusted in-flight to take advantage of unique situations.

Data syntheses are orchestrated by the Flight Data Engineer interacting with a minicomputer (16-bit word, 16K-word capacity coupled to twin, 100K-word floppy disks). The engineer can provide the research crew with any recorded or computed parameter via 20 digital and electromechanical displays, a hard-copy digital printer, and a six-channel, high speed, strip-chart recorder.

Data are recorded on both magnetic tape and disk media via serial digital, IRIG FM and direct recording. The disk record allows a detailed flight summary to be compiled immediately after landing at the airport using the small, onboard computer.

For this mission, the aircraft was configured for both cloud physics and aerosol research; the instrumentation layout is shown in Figure 1. Instruments for measuring basic parameters (temperature, dew point, pressure altitude, altitude above terrain, true airspeed, vertical and horizontal winds, aircraft altitude and rate of climb, turbulence and solar irradiance) are located primarily in the forward portion of the aircraft and are a permanent installation. A history of the aircraft flight path is provided by an x-y plotter which is driven by the aircraft navigational system; this provides a tracing of the aircraft position on a sectional map.

## AEROSOL INSTRUMENTATION

A schematic of the layout and ducting for the aerosol instrumentation is shown in Figure 2. The most complex portion is the aerosol sizing system which consists of four instruments:

1. The condensation nucleus counter (CNC)
2. The electrical aerosol analyzer (EAA)
3. Two optical particle counters (OPCs)

The instruments, completely integrated and controlled by the onboard computer, provide size spectral measurements of atmospheric aerosol from

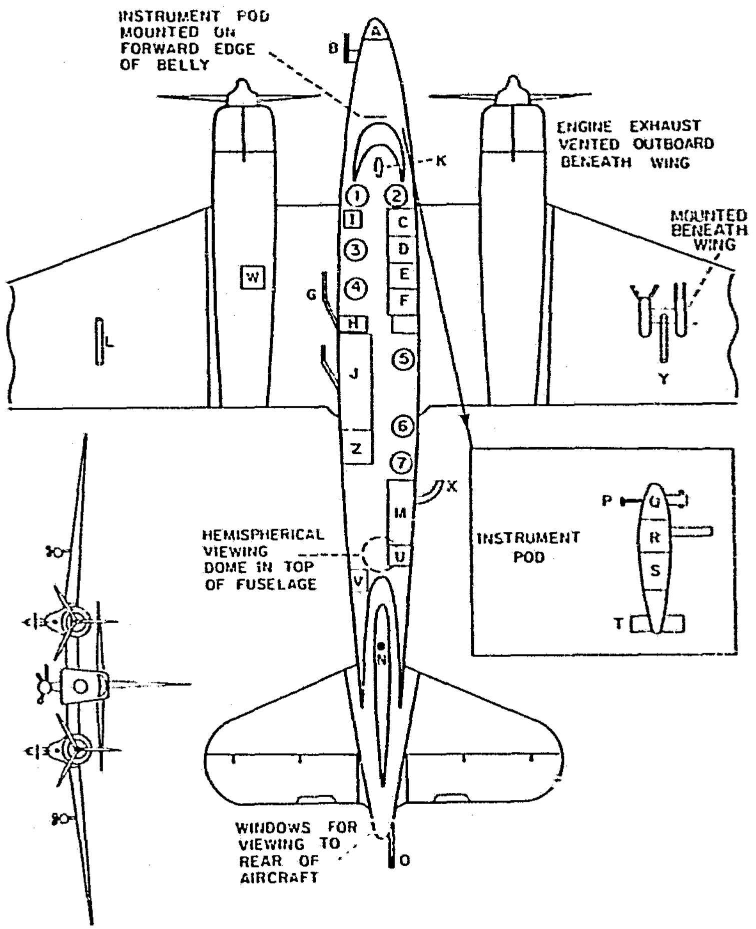


Fig. 1 Locations of crew and research instruments on the University of Washington's Douglas B-23 aircraft.

| | | | |
|---|---|---|---|
| 1-2 | Pilot and co-pilot | 5 | Aerosol Instrumentation Monitor I |
| 3 | Observer | 6 | Flight Scientist |
| 4 | Instrumentation Engineer | 7 | Aerosol Instrumentation Monitor II |

| | |
|---|---|
| A | 5-cm gyrostabilized weather radar. |
| B | Rosemount airspeed, pressure altitude and total temperature probes. MRI-turbulence probe and electronics, J-W liquid water probe, angle of attack sensor. |
| C | VOR-DME slaved position plotter; research power panel (3 KW 110V 60 Hz; 1.5 KW 110V 400 Hz; 150 amps 28V dc). |
| D | Electronic controls for J-W liquid water indicator, reverse housing thermometer, electrical cloud particle counter and dew point thermometer, time code generator and time display, WWV time standard receiver, TAS and $T_t$ analog computers, signal conditioning amplifiers, audio signal mixers, FSK time-share data multiplexers (63 channels), 2-D electric field and turbulence analog read-outs. |
| E | Minicomputer (16-bit word, 16k-word capacity), computer interface to instrumentation, remote A-D converter, keyboard and printer, floppy disks. |
| F | Analog digital tape recorder (7-track, 1/2") and high speed, 6-channel analog strip chart recorder. |
| G | Inlet for isokinetic aerosol sampling. |
| H | Aircraft oxygen, digital readout of all flight parameters, dew point sensor, time code reader and time display, heater aerosol plenum chamber, vertical velocity, Millipore sequential filter system. |
| I | Controls for metal foil impactor and continuous particle replicator. |
| J | Aerosol analysis section: integrating nephelometer, mass monitor, automatic cloud condensation nucleus counter, VHF air-to-ground transceiver, Whitby aerosol analyzer, Royco particle counters, NCAR manual condensation nucleus counter. |
| K | PMS axially-scattering spectrometer (small droplet probe), vertically mounted. |
| L | Bomb rack hard point suitable for small instrument pods. |
| M | Ice nucleus counter (NCAR). |
| N | Hemispheric UV sensor. |
| O | Electric field mill sensor (vertical and horizontal field). |
| P | Reverse flow static temperature probe. |
| Q | Automatic ice particle counter and metal foil hydrometeor impactor. |
| R | MRI continuous particle replicator. |
| S | Tracer ejection pyrotechnic racks (52 40mm units). |
| T | Tracer pyrotechnic rack (24 1.5" units). |
| U | Radar repeater, side viewing automatic camera. |
| V | Radar altimeter, 3-D electric field mill electronics, 20-channel telemetry transmitter. |
| W | Instrument vacuum system (consists of six high-capacity vacuum pumps connected connected individually to the cabin). |
| X | Anisokinetic large volume aerosol sampler. |
| Y | PMS optical array precipitation spectrometer. PMS optical array cloud droplet probe. |
| Z | Ice nucleus counter (Mee), ice nucleus filters, [illegible] counter. |

FIGURE 1. Plan View of Instrumentation Onboard the University of Washington's Douglas B-23 Aircraft.

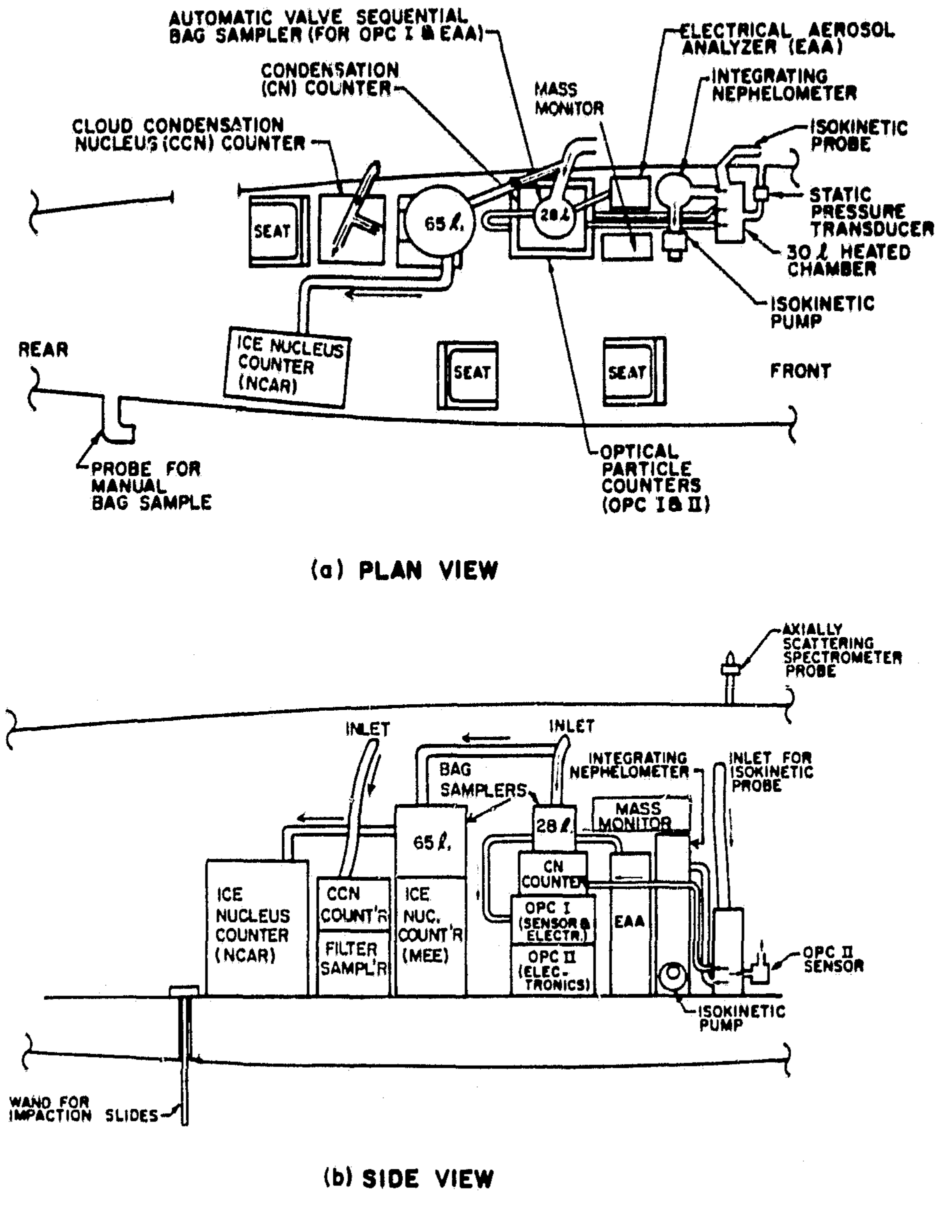


FIGURE 2. Plan and Side Views of Aerosol Instrumentation on the University of Washington's Research Aircraft.

0.01 to 65 μm in diameter over a concentration range of $10^{-6}$ to $10^{7}$ $cm^{-3}$. These instruments have been extensively modified in the laboratory at the University of Washington to provide optimum performance and they are regularly calibrated. A description of the CNC, EAA, and OPCs and their installation in the B-23 has been given by Hobbs and others.[4]

The sampling system as shown in Figure 2 is configured for measuring transient deviations in aerosols (such as those encountered in plumes or clouds). Consequently, air samples are taken in rapidly and automatically by a "grab-bag" sampling system. In addition to the grab-bag sampling (which is not completely isokinetic), an isokinetic sampling system is used. Both sampling systems condition the aerosol to a nearly constant relative humidity (<60%). [OPC I, EAA, and mass monitor sample is dried by a diffusion drier; OPC II and nephelometer sample is drawn from the 30 ℓ heated chamber.]

A general index of the air pollution is obtained using an integrating nephelometer,[4] the automatic CNC, and an oscillating crystal mass monitor.[5]

Since the major interests in this study were the concentrations of atmospheric IN and CCN, some modifications were made to expand the B-23 capabilities in this portion of the instrumentation. An NCAR IN counter was installed aft of its usual location, allowing room for an operator. The Naval Weapons Center (NWC) Mee IN counter was installed where normally the University of Washington automatic CCN counter is mounted. The automatic CCN counter was replaced with a manual NCAR CCN counter. In addition, a multi-filter manifold was added for measuring IN by the Millipore filter method. The IN counters, the NCAR CCN counter, and the filters were calibrated in the laboratory prior to the flight.[3]

## CLOUD PHYSICS INSTRUMENTATION

The cloud physics instrumentation on the B-23 is designed to provide comprehensive measurements of the sizes, spatial distributions, and physical characteristics of solid and liquid cloud and precipitation particles. This information is provided by seven different instruments:

1. Data on solid hydrometer characteristics (e.g. crystal type, degree of rimming and aggregation) are provided by impaction and Formvar plastic replication.[6]

2. Similar information for mm-size solid and liquid particles is provided by impact markings on the thin, metal foil of the foil sampler.[7]

3. The size spectra (concentration versus maximum particle dimensions) of cloud and precipitation particles over the size range 3 to 4500 μm are provided by three Particle Measuring Systems (PMS) laser probes.[8] Unlike the impaction devices the PMS data are processed and

displayed in real-time in the aircraft by the computer. Computed values of the effective radar reflectivity and precipitation rate (assuming spherical particles) are also calculated and displayed.

4. Cloud liquid water content is measured directly by a hot-wire sensor (Johnson-Williams device) and is also computed from the PMS data.

5. Ice crystal concentrations are measured by a laser depolarization device developed at the University of Washington.

An overall view of the spatial distribution of precipitation is provided by a 5-cm gyrostabilized weather radar.

The specifications of all the instrumentation for the aircraft is given in Appendix A (some of the instrumentation listed was not aboard during this experiment).

## MEASUREMENTS, RESULTS, AND DISCUSSION

Descriptions of all of the flights for this project are given in Table 1. During portions of the ferry and project flights, measurements were made of the ambient aerosol. These measurements illustrate both the capabilities of the research system aboard the B-23 and provide some information on the "background" aerosol over the Florida peninsula during periods when the region was experiencing a rather polluted northern continental air mass. A few measurements were also made in the smoke plumes from a number of brush fires in the area of KSC.

### AEROSOL PARTICLE AND CCN MEASUREMENTS

Figure 3 shows the aerosol size distribution near Ft. Collins on 15 March 1978 taken during the test flight of the NCAR and Mee IN counters. Sampling at 800 m above ground level (AGL) (777 mb), the total particle concentration was rather high ($\sim 10^6$ $cm^{-3}$), indicating the presence of either fresh anthropogenic aerosol or gas-to-particle conversion products. However, particle concentrations decreased rapidly with increasing particle size. The rather good visibility which was observed is reflected in the low concentrations of 0.1 to 1 μm particles. The large expanse of exposed soil in the area produced significant numbers of particles as large as ~8 μm in diameter (strong northerly winds and dust devils were observed during the flight).

On the flight from Little Rock to Patrick AFB on 16 March 1978 measurements were taken near Little Rock at an altitude of 500 m AGL (957 mb) in visually polluted air. Figure 4 shows that the concentrations

TABLE 1. B-23 Flight Operations.

| Date | Destination | Mission |
|---|---|---|
| 13 March 1978 | Ft. Collins, Colo. | Ferry aircraft from Seattle. |
| 15 March 1978 | Loveland, Colo. | Test flight to check out NCAR and Mee IN counters (installed in Ft. Collins). |
| 15 March 1978 | Little Rock, Ark. | Ferry aircraft from Loveland. |
| 16 March 1978 | Patrick AFB, Fla. | Ferry aircraft from Little Rock. Heavily polluted air mass, some en route sampling. |
| 17 March 1978 | Patrick AFB, Fla. | Pre-launch test flight. Interesting "background" data taken as well as samples from brush fire plumes. |
| 23 March 1978 | Patrick AFB, Fla. | "Background" aerosol data in vicinity of KSC. |
| 24 March 1978 | Boulder, Colo. | Ferry from Patrick AFB. Instruments returned to NCAR and NWC. |
| 25 March 1978 | Seattle, Wash. | Ferry from Boulder, Colo. |

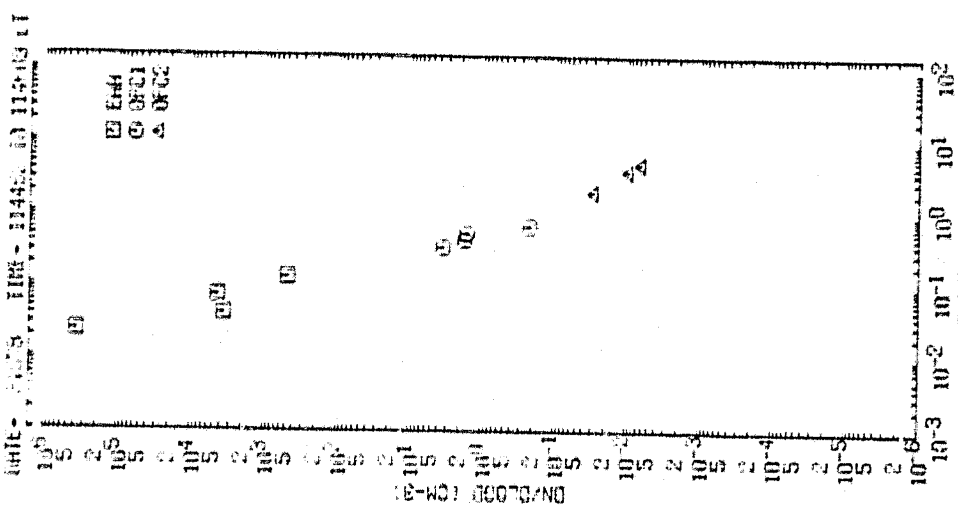


**FIGURE 3.** Aerosol Size Distribution Measured at 800 m AGL Near Ft. Collins, Colo.

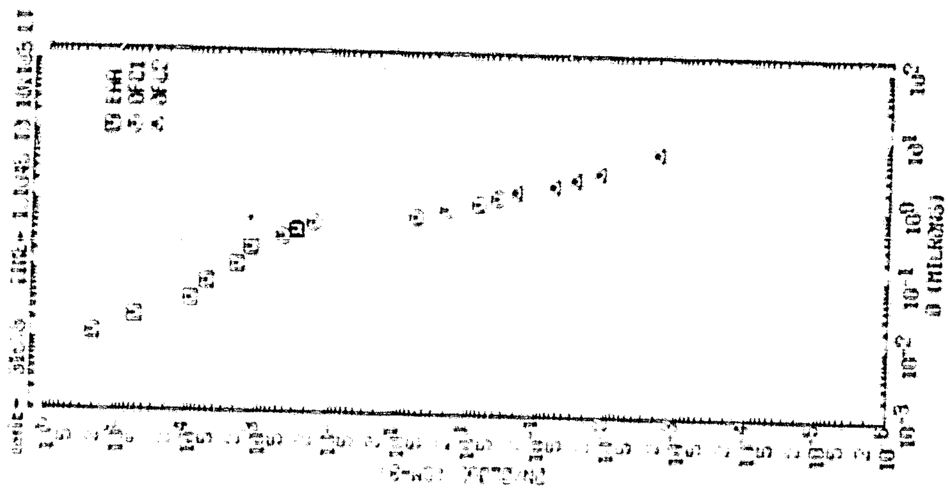


**FIGURE 4.** Aerosol Size Distribution Measured at 500 m AGL in a Polluted Air Mass Near Little Rock, Ark.

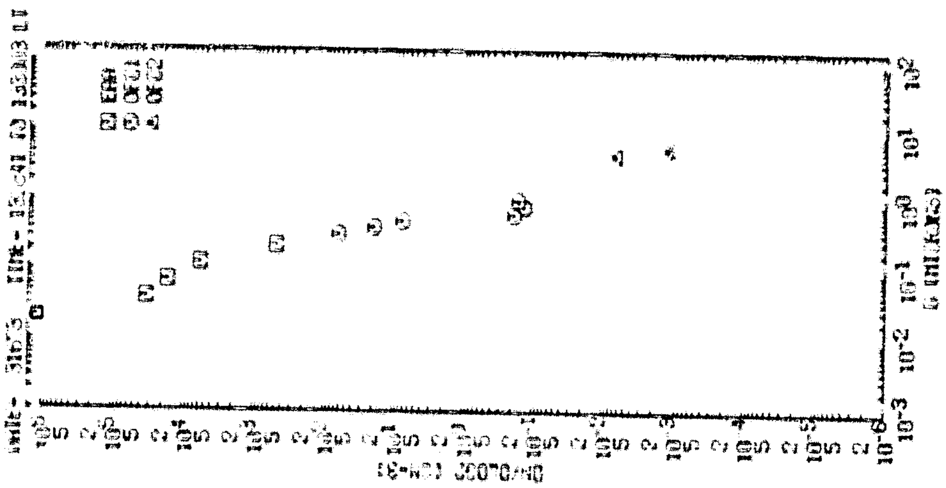


**FIGURE 5.** Aerosol Size Distribution Measured at 2000 m AGL Near Patrick AFB, Fla.

of the particles in the optically important size range (0.1 to 1 μm) were more than 2 orders of magnitude greater than those measured at Ft. Collins, but the larger micron-sized particles were present in concentrations similar to those measured at Ft. Collins.

Later on 16 March 1978 (1328 EST), approaching Patrick AFB in bright, midday sunshine, the particle measurements made at 2,000 m AGL (787 mb) show possible effects of photochemistry (Figure 5). The concentrations of the smallest aerosol ($\sim 10^{-2}$ μm) were an order of magnitude greater than those measured near Little Rock, but the size distribution of the remainder of the aerosol was similar to that measured at Little Rock. The larger concentrations of the $10^{-2}$ μm particles may have been due to gas-to-particle conversion in air, rich in trace gases, flowing from the northwest across the continental United States (Figure 6).

One of the characteristics of such a polluted, aged air mass can be seen in Figure 7 where the data from Figure 5 are replotted as a particle volume distribution. It can be seen that this plot is distinctly trimodal. Such a distribution is normally interpreted as follows: the particles in the smallest size mode (0.01 to 0.1 μm) represent particle production by either gas-to-particle conversion or by fresh high-temperature combustion processes; the particles in the middle size mode (0.1 to 1 μm, often called the "accumulation mode") are a mixture of long-lived, directly-emitted particles and the coagulation products of smaller particles, and the particles in the large size mode (>1 μm, called the "coarse particle mode") are mostly short-lived aerosol produced directly from the earth's surface by mechanical processes.

The following day (17 March 1978), while practicing aircraft prelaunch procedures in the vicinity of KSC, measurements were taken in the same polluted air mass that was sampled on 16 March as well as in smoke plumes from brush fires. The size distributions of the aerosol samples from the polluted air mass (Figures 8 and 9) taken at 1,000 m AGL (917 mb) are similar to the measurements taken on 16 March. Measurements of the CCN concentrations from the polluted air mass on 17 March are shown in Figure 10. The CCN measurements were fitted to an expression of the form:

$$N = cS^k$$

where N is the CCN concentration ($cm^{-3}$), c and k are empirical constants, and S the supersaturation in percent. For the measurements shown in Figure 10 the values of c and k were 3,000 $cm^{-3}$ and 1.1, respectively. These values are typical for measurements in polluted air masses in the eastern United States as reported by Radke and Hobbs.[3] The remainder of the CCN data are given in Table 2. The CCN concentration reported here are greater than those measured in background air at KSC in August, September 1977.[1]

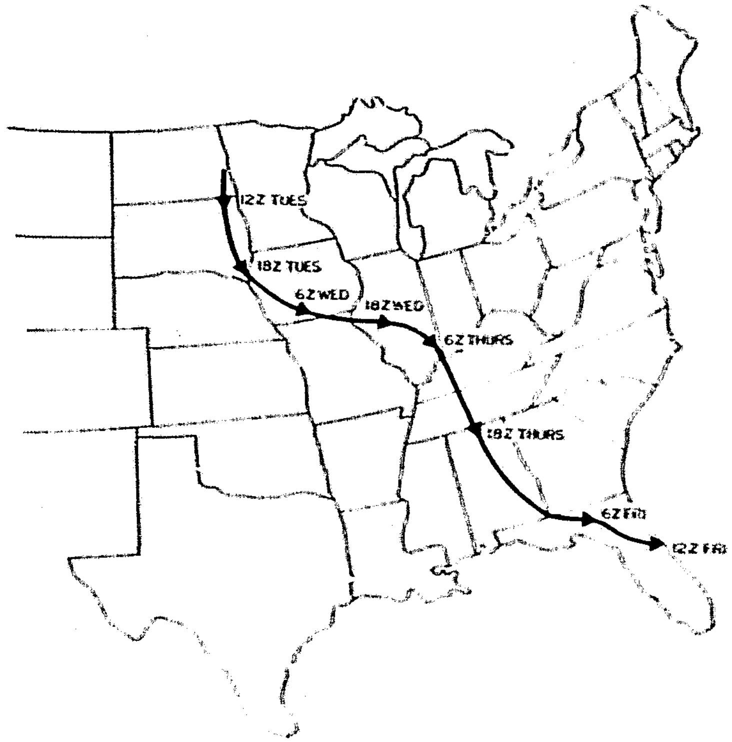


FIGURE 6. The 850 mb Trajectory Analysis (72-hr) for Patrick AFB, Fla., on 17 March 1978.

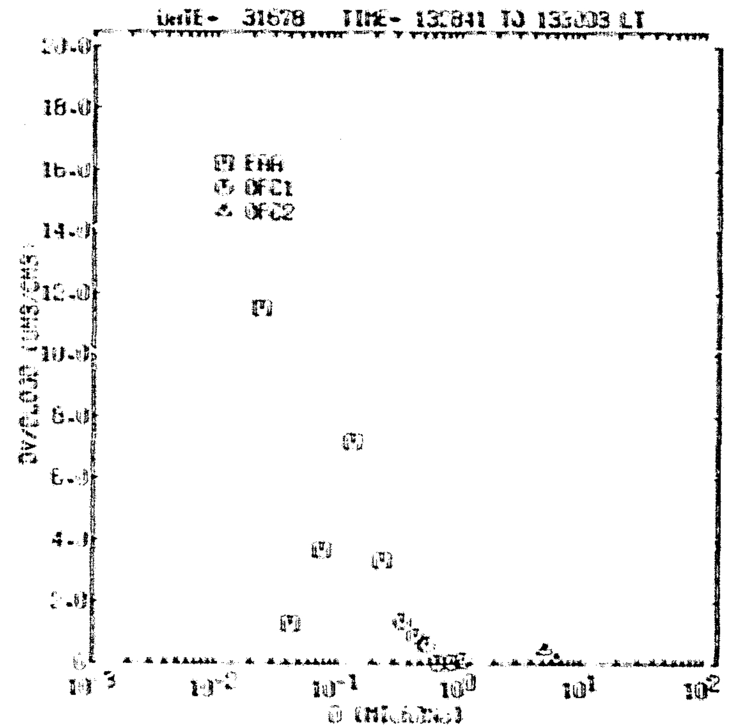


FIGURE 7. The Aerosol Volume Distribution Corresponding to Figure 5 Showing a Trimodal Character.

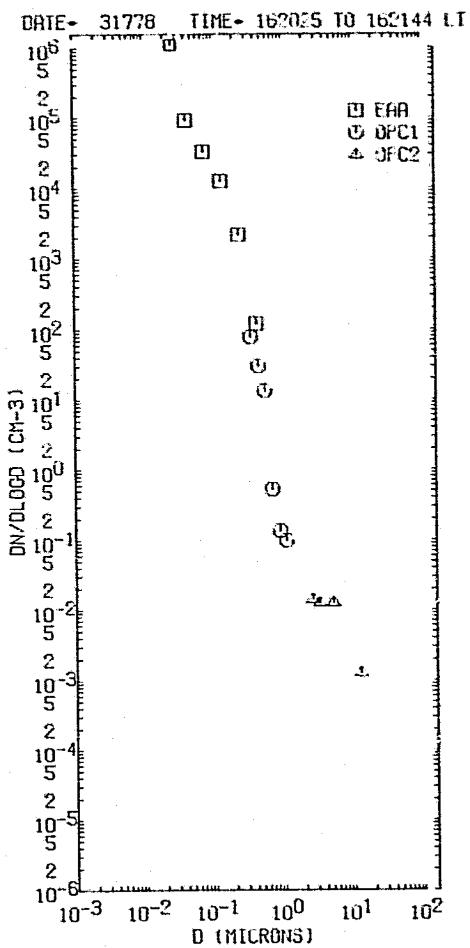


FIGURE 8. Aerosol Size Distribution Measured at 1000 m AGL Northwest of the Kennedy Space Center.

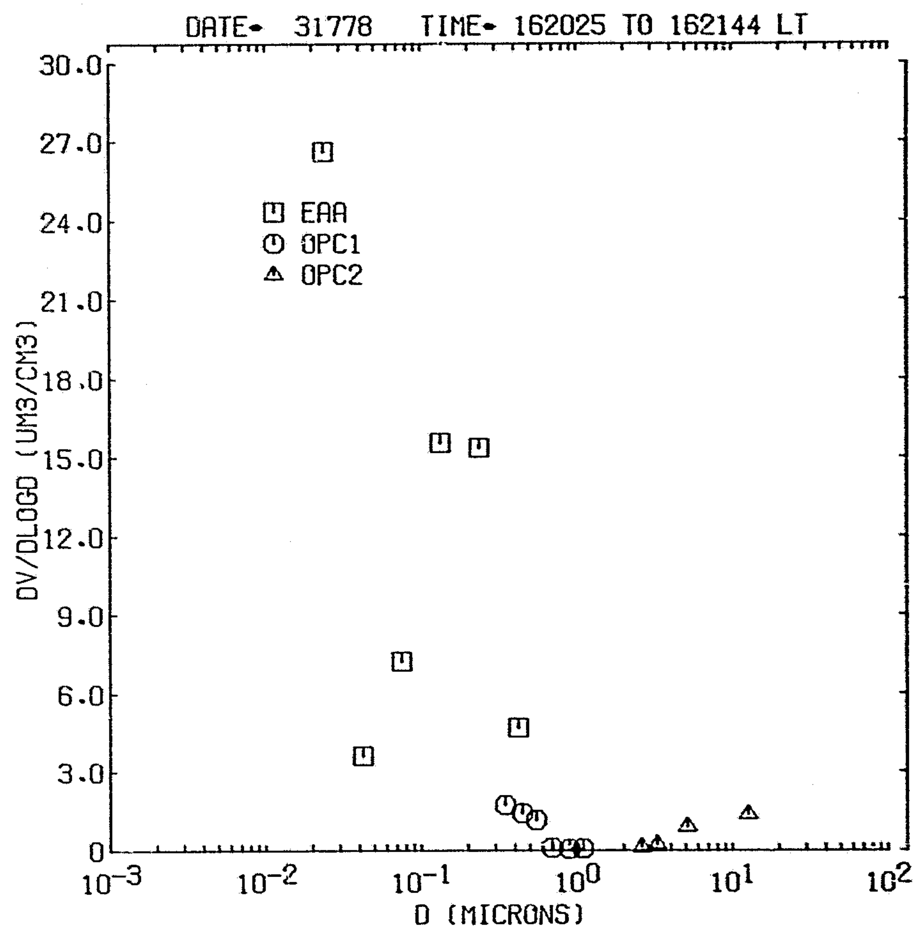


FIGURE 9. The Aerosol Volume Distribution Corresponding to Figure 8.

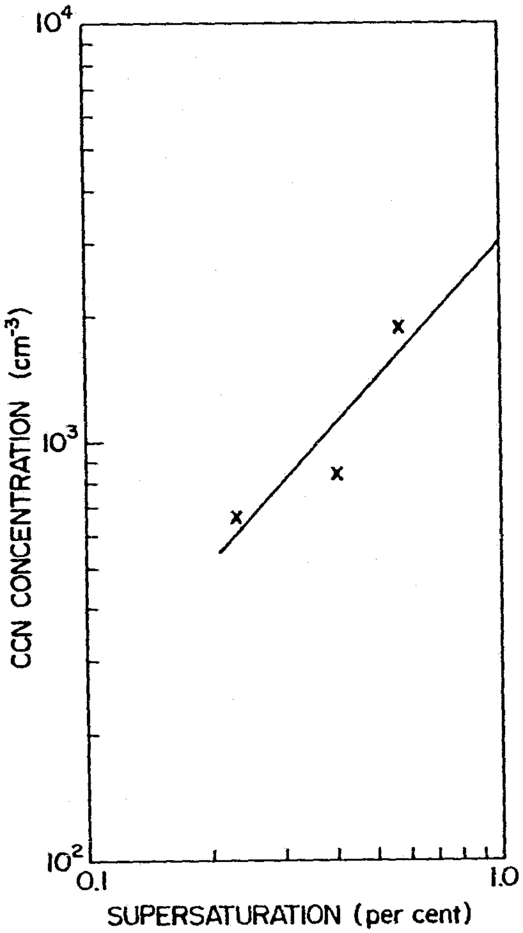


FIGURE 10. Cloud Condensation Nucleus Spectrum Corresponding to the Aerosol Size Distribution Shown in Figure 8 (1620 EST, 17 March 1978).

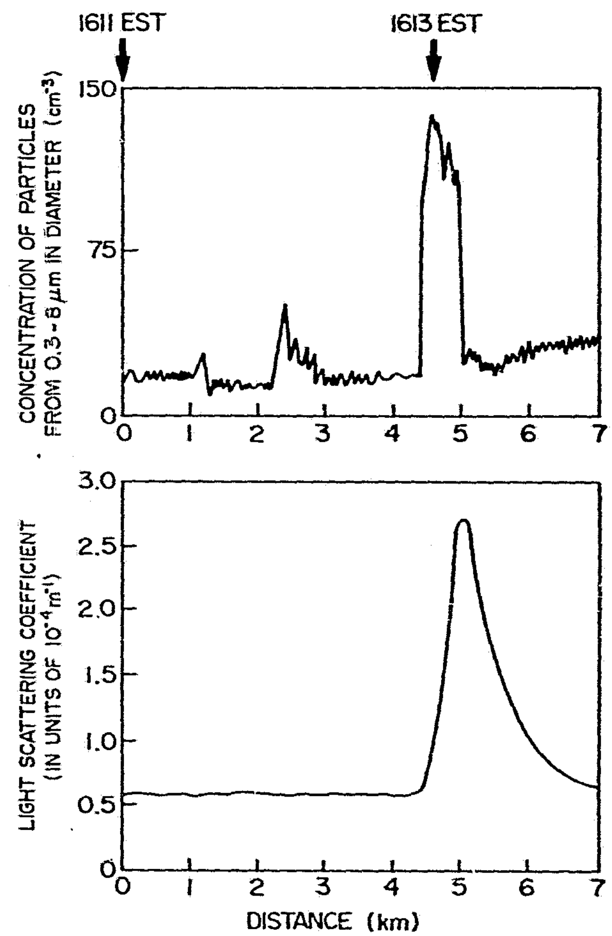


FIGURE 11. Aerosol Measurements in the Smoke Plume From a Brush Wildfire. Measurements were obtained at an altitude of 1000 m about 4 km downwind of the fire.

TABLE 2. CCN Data.

| 16 March 1978 | | | | 17 March 1978 | | | |
|---|---|---|---|---|---|---|---|
| Flight to Patrick AFB | | | | Flight at KSC | | | |
| Time (EST) | S[a] (%) | N ($cm^{-3}$) | Remarks[b] | Time (EST) | S[a] (%) | N ($cm^{-3}$) | Remarks[b] |
| 1309 | .21 | 1680 | Free-stream | 1544 | .23 | 1350 | Free-stream |
| 1310 | .23 | 1650 | Free-stream | 1548 | .40 | 1390 | Free-stream |
| 1320 | .22 | 1090 | Free-stream | 1553 | .56 | 2140 | Free-stream |
| 1324 | .31 | 0396 | Bag | 1617 | .23 | 0660 | Bag[c] |
| 1327 | .57 | 0264 | Free-stream | 1618 | .40 | 0825 | Free-stream[c] |
| 1330 | .70 | 0429 | Free-stream | 1620 | .56 | 1848 | Free-stream[c] |
| 1333 | .58 | 0495 | Free-stream | 1628 | .46 | 2310 | Free-stream |
| 1336 | .38 | 0363 | Free-stream | | | | |
| 1338 | .26 | 0561 | Free-stream | | | | |
| 1355 | .20 | 0561 | Free-stream | | | | |
| 1357 | .21 | 0396 | Free-stream | | | | |
| 1401 | .40 | 0495 | Free-stream | | | | |
| 1405 | .58 | 1390 | Free-stream | | | | |
| 1414 | .39 | 0462 | Free-stream | | | | |
| 1408 | .38 | 2010 | Free-stream | | | | |
| 1422 | .40 | 1980 | Free-stream | | | | |

[a] S means supersaturation with respect to water.

[b] Free-stream sample means the CCN instrument was sampling outside air, bag sample means outside air was grab-sampled with a bag and then monitored with the instrument.

[c] Plotted in Figure 10.

Measurements in the smoke plumes from brush fires on 17 March were made also at 1,000 m altitude. A typical set of measurements from the integrating nephelometer and from the rate meter on OPC I is shown in Figure 11. The measured particle size distribution for this smoke sample (Figure 12) shows that the concentrations of particles 0.3 to 1 μm in size were about an order of magnitude greater than in the "background" air (see Figure 8) and that particles $\sim 10^{-2}$ μm in diameter were also present in large concentrations. Such high concentrations of $10^{-2}$ μm particles are somewhat surprising from a presumably low-temperature fire. However, as we have previously observed in smokes from woody, biomass fires, most of the aerosol volume (mass) is contained in the accumulation mode. The measurements on 17 March (Figure 13) are consistent with this observation.

During our stay in Florida we made no cloud particle measurements. However, to demonstrate the B-23 capabilities in this area, Figure 14 illustrates the cloud particle size distribution measured in a precipitating, marine cumulus near Seattle.

## IN MEASUREMENTS

Airborne measurements of 17 and 23 March and ground measurements of 22 March from the membrane filters are summarized in Table 3. Measurements were made at -20, -16, and -12C at a supersaturation (with respect to water) of approximately 6%. Similar concentrations were obtained with both the Sartorius and Millipore filters.

Figures 15 and 16 show the counts plotted as a function of temperature. The IN activity dropped only an order of magnitude from -20 to -12C (ordinarily a change of 2 orders of magnitude would be expected, but the validity of the rule on which this assumption is based is not well founded). The IN concentration reported in Figures 15 and 16 are consistent with IN concentrations measured in background air at KSC in August, September 1977.[1]

The counts were relatively high for a number of samples; in fact, they are not much lower than ice crystal concentrations observed on FACE (Florida Area Cumulus Experiment) by Sax.[10] The low counts of 17 March were collected in air over land, while the high counts of 22 March were taken on the ground near the beach in a steady breeze from the ocean. The 23 March samples (Figure 16) show both high and low counts. Further analysis may reveal that these relate to the altitudes at which the samples were obtained and to the source of the air (over land versus over water).

Figures 17 and 18 show a comparison of the filter counts with those from the NCAR and Mee counters (continuous counts). The 23 March filter counts are in good agreement with the continuous counts, even on an

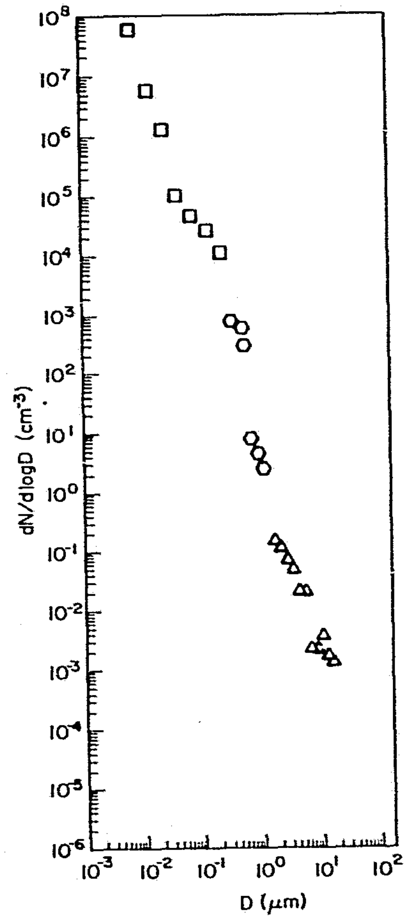


FIGURE 12. Aerosol Size Distribution of the Smoke From a Wild Brushfire Monitored on 17 March 1978 Between 162958 and 163005 EST.

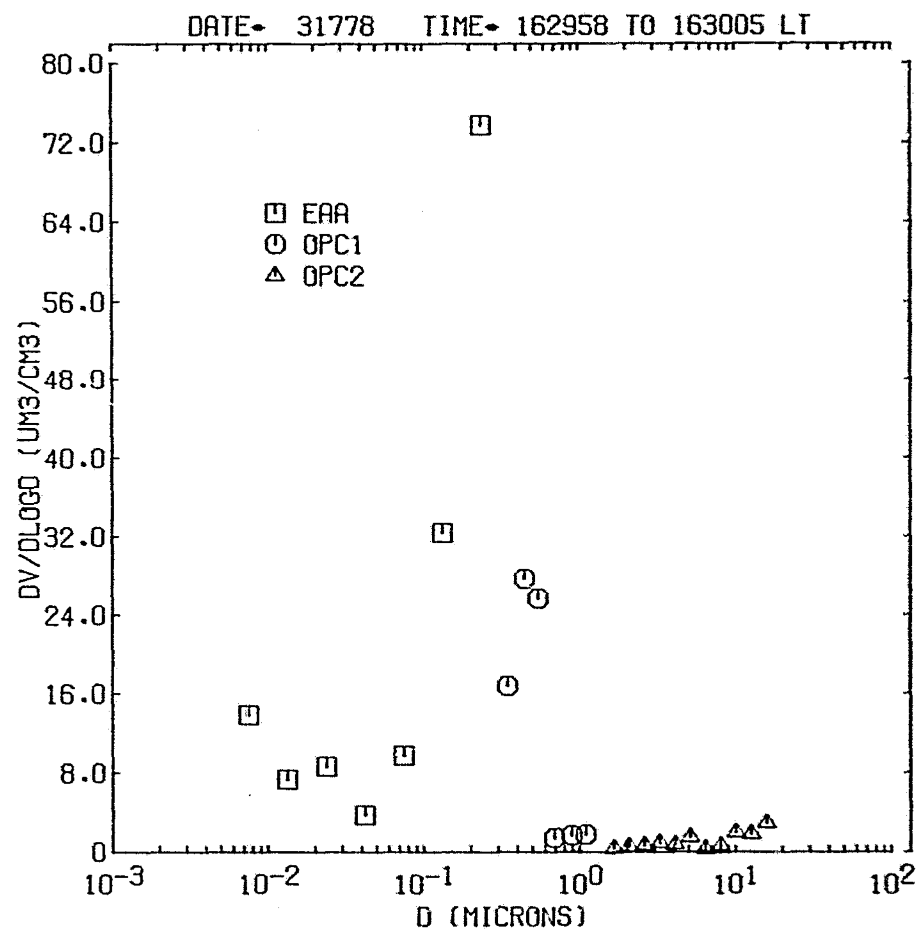


FIGURE 13. Aerosol Volume Distribution Corresponding to Figure 12.

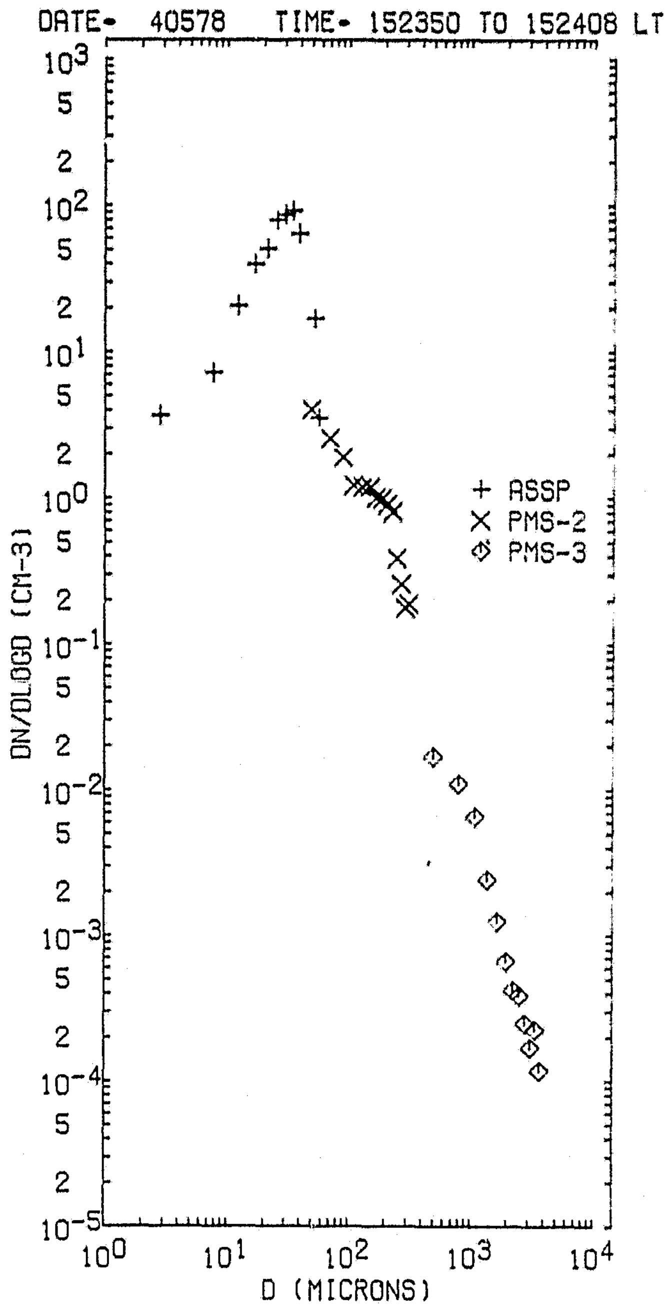


FIGURE 14. An Example of the cloud particle Size Distribut n Measured With PMS Probes in a Precipi ... Maritime Cumulus Cloud Near Seattle

TABLE 3. Florida Membrane Filter Data.

| Date | Type/no. | Time (EST) | Vol ($\ell$) | −20C $\Delta T$ = 3C | | −16C $\Delta T$ = 3C | | −12C $\Delta T$ = 2.5 | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Count | Conc ($\ell^{-1}$) | Count | Conc ($\ell^{-1}$) | Count | Conc ($\ell^{-1}$) |
| 3-17 | SA 1 | 1520-1630 | 420 | 42 | 0.10 | 24 | 0.06 | 0 | 0 |
| 3-17 | SA 2 | 1520-1630 | 350 | 20 | 0.06 | 16 | 0.05 | 4 | 0.01 |
| 3-17 | HA P2 | 1520-1630 | 560 | 20 | 0.04 | 24 | 0.04 | 0 | 0 |
| 3-17 | HA P4 | 1520-1630 | 350 | 68 | 0.19 | 24 | 0.07 | 32 | 0.09 |
| 3-22 | SA 3 | 1559-1609 | 108 | 108 | 1.00 | 16 | 0.15 | 8 | 0.07 |
| 3-22 | SA 4 | 1609-1629 | 216 | 356 | 1.65 | 104 | 0.48 | 4 | 0.02 |
| 3-22 | HA A | 1630-1640 | 160 | 552 | 3.45 | 76 | 0.48 | 36 | 0.27 |
| 3-22 | HA B | 1642-1702 | 320 | 700 | 2.19 | 100 | 0.31 | 48 | 0.15 |
| 3-23 | SA 5 | 1626-1636 | 30 | 212 | 7.07 | 128 | 4.27 | 84 | 2.80 |
| 3-23 | SA 6 | 1626-1636 | 70 | 92 | 1.31 | 76 | 1.09 | 56 | 0.80 |
| 3-23 | HA 6 | 1637-1647 | 136 | 80 | 0.59 | 8 | 0.06 | 16 | 0.12 |
| 3-23 | HA 7 | 1647-1651 | 54 | 24 | 0.44 | 0 | 0 | 4 | 0.07 |
| 3-23 | HA 8 | 1658-1703 | 68 | 36 | 0.53 | 24 | 0.35 | 4 | 0.06 |
| 3-23 | HA 9 | 1704-1714 | 136 | 44 | 0.32 | 4 | 0.03 | 0 | 0 |
| 3-23 | HA 10 | 1717-1720 | 41 | 36 | 0.88 | 4 | 0.10 | 0 | 0 |
| 3-23 | SA 8 | 1723-1733 | 108 | 504 | 4.67 | 156 | 1.44 | 44 | 0.41 |
| 3-23 | SA 9 | 1734-1739 | 54 | 444 | 8.22 | 192 | 3.56 | 60 | 1.11 |
| 3-23 | SA 11 | 1807-1817 | 136 | 104 | 0.76 | 24 | 0.18 | 8 | 0.06 |
| 3-23 | SA 12 | 1818-1828 | 136 | 72 | 0.53 | 28 | 0.21 | 8 | 0.06 |
| 3-23 | SA 12A | 1844-1904 | 272 | 336 | 1.24 | 52 | 0.19 | 4 | 0.01 |
| 3-23 | SA 13 | 1913-1918 | 68 | 20 | 0.29 | 12 | 0.29 | 0 | 0 |

NOTE: SA = Filters from SUNYA made by Sartorius.
HA = Filters from UW Supply made by Millipore, 0.45 μ gridded.

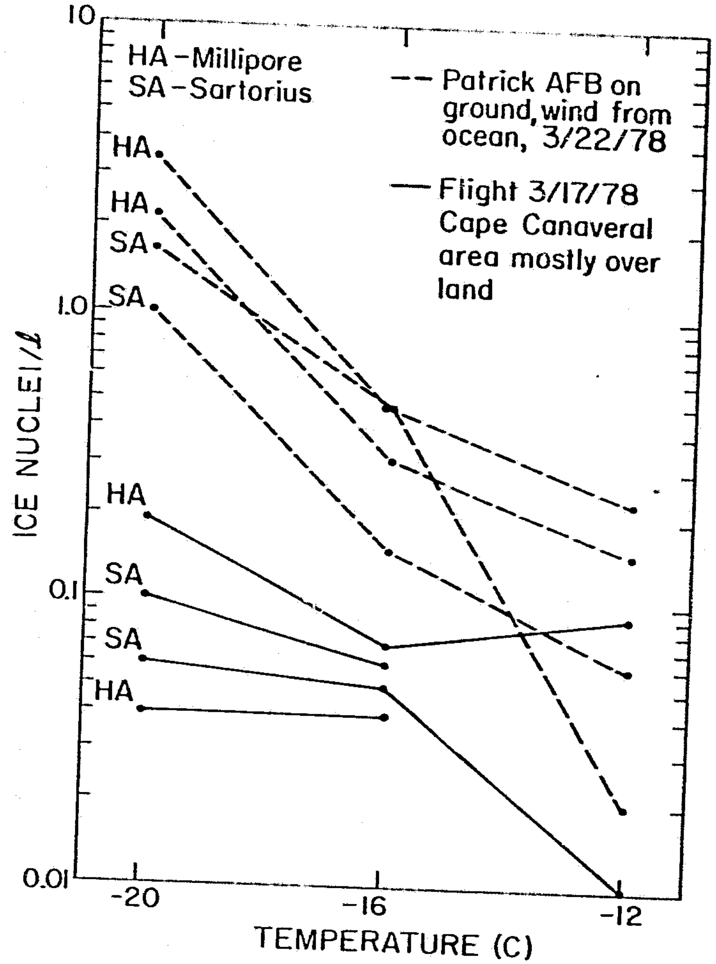


FIGURE 15. Membrane Filter Ice Nucleus Data for 17 and 22 March 1978.

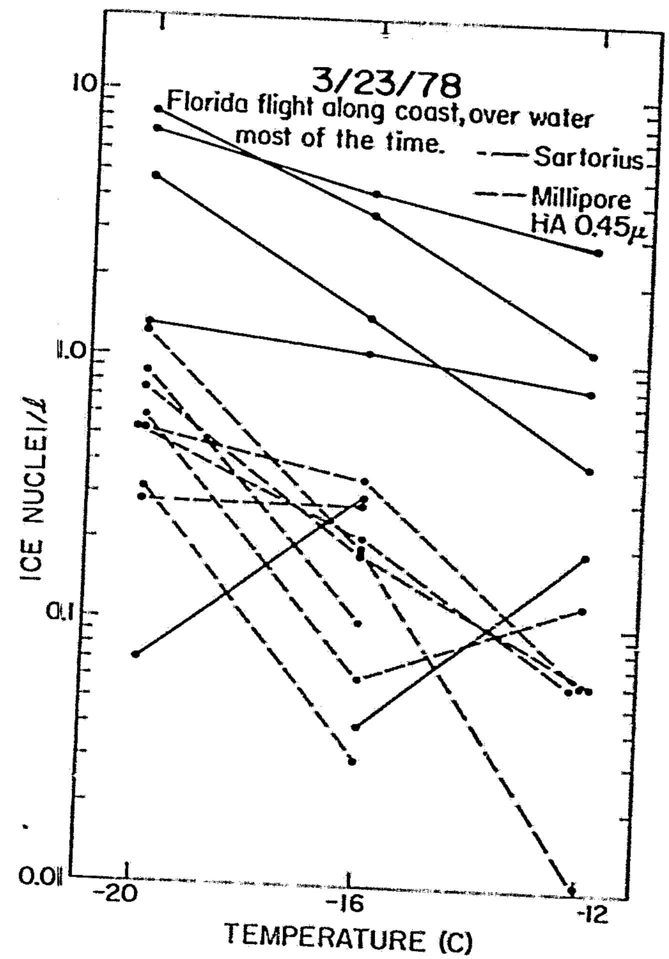


FIGURE 16. Membrane Filter Ice Nucleus Data for 23 March 1978 Flight Along the Coast.

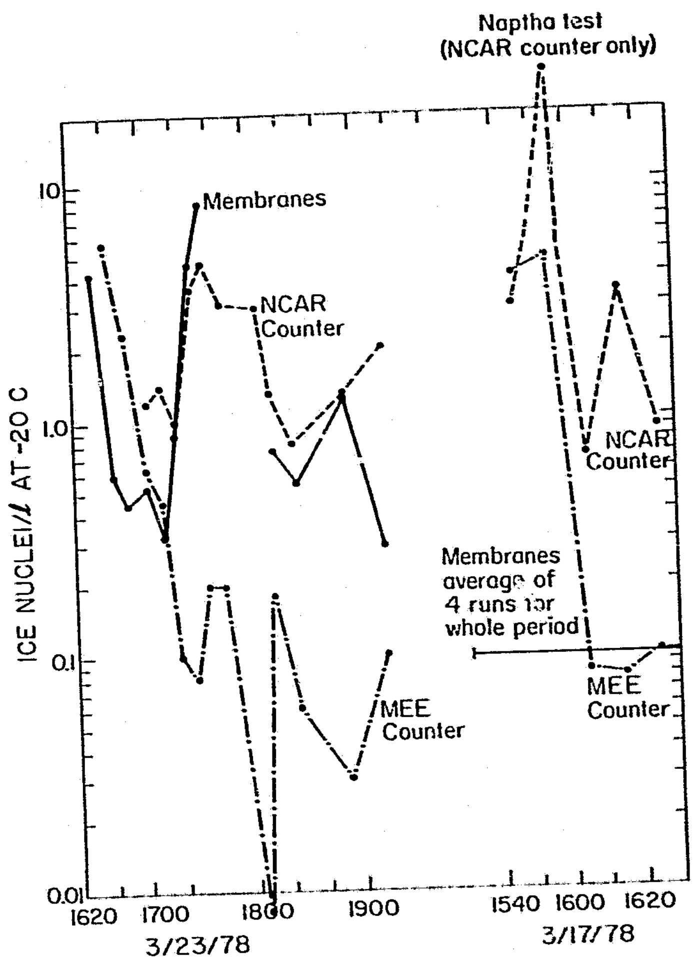


FIGURE 17. Correlation Between Ice Nucleus Counts Derived From Membranes, NCAR Counter, and Mee Counter.

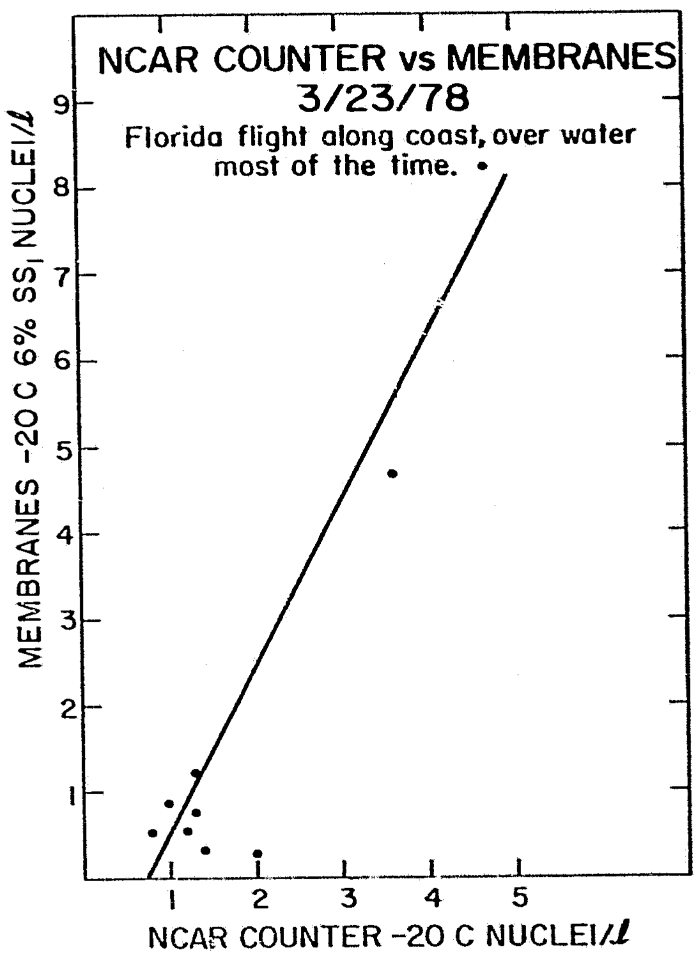


FIGURE 18. Correlation Between Ice Nucleus Counts From Membranes and NCAR Counter.

absolute basis. However, in the 17 March data, the filter counts are much lower than those from the NCAR counter. In this flight only four parallel filter samples were taken for the entire period, resulting in large sample volumes and the possibility that some of the nuclei may have been suppressed by the concurrently collected aerosol particles. The fact that both the highest and lowest counts were from the smallest volume appears to discount the possible adverse effect of large sample volume (see Table 3). Further, during Project FACE, hundreds of membrane filter samples were taken over the peninsula and these invariably gave much lower counts than the NCAR counter. It can be speculated that for the 17 March sampling over land, the NCAR counter was not influenced by the apparent "suppression effect" as was the membrane filter.

Using Figure 17, the counts from the NCAR and Mee instruments can be compared. During the early part of the flights, the two instruments gave similar counts, but as the flights progressed, the Mee counts became lower than the NCAR counts. An examination of the operating variables of the Mee counter (given in Table 4) may explain this decrease. The chamber temperature ($T_{sump}$) remained constant throughout the flight (except when it was cooling), but the inlet air temperature ($T_{inlet}$) decreased significantly. When $T_{inlet}$ was high, the trigger level also had to be set high to avoid counting cloud droplets. When $T_{inlet}$ was low, the trigger level could be set low and not count droplets. This indicates that the moisture content of the cloud decreased with decreasing $T_{inlet}$. A decrease in moisture would have inhibited ice crystal formation and growth and would have led to suppressed IN counts in the Mee counter.

A few tests with the NCAR IN counter were performed on the ground at Patrick AFB. The IN counter remained in the aircraft. Milligram-sized pieces of Shuttle solid propellant were burned in a small container. Very little activity at -20C was observed in contrast to the tests at Colorado State University.[3] Recently similar pieces were tested at the NCAR. Some pieces showed a lack of activity and some showed considerable activity. Clearly, much more research should be carried out in the laboratory on the properties of the propellant as a source of IN.

## CONCLUSIONS

The airborne measurement facility was used to obtain aerosol particle sizes and concentrations at Ft. Collins, Little Rock, and in the vicinity of Kennedy Space Center (KSC); IN and CCN measurements were made in the vicinity of KSC. Significant differences in particle concentrations were measured between clean air over Ft. Collins and considerably dirtier air over Little Rock and KSC. The air mass over KSC originated in the high plains region 3 days earlier. The air over Ft. Collins was probably

TABLE 4. Data From the Mee Ice Nucleus Counter.

| Date | Time Interval (EST) | Average Conc. ($\ell^{-1}$) | $T_{sump}$ (C) | $T_{inlet}$ (C) | Flow ($\ell$ min$^{-1}$) | Trigger level (mv) | Remarks |
|---|---|---|---|---|---|---|---|
| 3-23 | 1626-1536 | 6.6 | -11.0 | 28.0 | 10 | 10.0 | Chamber cooling down |
| 3-23 | 1637-1647 | 5.7 | -18.0 | 26.8 | 10 | 11.0 | |
| 3-23 | 1647-1651 | 2.3 | -19.0 | 27.4 | 10 | 13.0 | |
| 3-23 | 1658-1709 | 0.63 | -20.4 | 23.7 | 10 | 13.0 | Inlet air temperature slowly changing; trigger level adjusted as cloud density decreased. |
| 3-23 | 1709-1714 | 0.45 | -20.5 | 23.3 | 10 | 13.0 | |
| 3-23 | 1717-1720 | 0.10 | -20.5 | 23.5 | 10 | 14.0 | |
| 3-23 | 1723-1733 | 0.08 | -20.4 | 22.2 | 10 | 13.0 | |
| 3-23 | 1734-1739 | 0.20 | -20.9 | 21.7 | 10 | 12.0 | |
| 3-23 | 1740-1750 | 0.20 | -20.4 | 20.7 | 10 | 11.0 | |
| 3-23 | 1801-1806 | 0.0 | -20.5 | 20.0 | 10 | 11.0 | |
| 3-23 | 1807-1817 | 0.18 | -20.5 | 19.0 | 10 | 10.0 | |
| 3-23 | 1818-1828 | 0.06 | -20.6 | 18.2 | 10 | 10.0 | |
| 3-23 | 1844-1904 | 0.03 | -20.8 | 18.0 | 10 | 10.0 | |
| 3-23 | 1913-1918 | 0.10 | -20.2 | 17.6 | 10 | 8.0 | |
| 3-17 | 1520-1530 | --- | --- | --- | --- | --- | --- |
| 3-17 | 1530-1540 | --- | --- | --- | --- | --- | |
| 3-17 | 1540-1550 | 4.0 | -19.8 | 21.1 | 10 | 10.0 | |
| 3-17 | 1550-1600 | 4.8 | -20.1 | 19.9 | 10 | 10.0 | |
| 3-17 | 1600-1610 | 0.084 | -20.6 | --- | 10 | 11.0 | Note trigger level change |
| 3-17 | 1610-1620 | 0.080 | -20.7 | --- | 10 | 11.0 | |
| 3-17 | 1620-1630 | 0.10 | -20.8 | --- | 10 | 11.0 | --- |

representative of the air in the high plains region and became increasingly dirtier as it flowed south-eastward toward KSC due to numerous sources of natural and man-made particles. The CCN measurements at KSC were typical of polluted eastern seaboard air. The CCN concentrations were greater than the CCN concentrations obtained KSC in August, September 1977.

IN concentrations were measured using NCAR and Mee portable IN counters and filter devices. The data from the NCAR and filter devices correlated satisfactorily. The data from the NCAR and Mee counters correlated satisfactorily until the Mee counter inlet air cooled significantly. The concentrations of IN detected with the filters are similar to concentrations measured at KSC in August, September 1977. Filter derived IN concentrations reported here were systematically lower over the land and higher over the sea. This difference in IN concentrations may be related to the source of the air and warrants further investigation.

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# Appendix A

## SPECIFICATIONS OF RESEARCH INSTRUMENTS ON THE B-23 AIRCRAFT

TABLE A-1

SPECIFICATIONS ON RESEARCH INSTRUMENTS ON THE UNIVERSITY OF WASHINGTON'S B-23 AIRCRAFT

| Parameter | Instrument Type | Manufacturer and Model No. | Range | Error | Time Constant | On-Board Recorded? | Power Requirements | Remarks |
|---|---|---|---|---|---|---|---|---|
| Total air Temperature ($T_{TOT}$) | Platinum wire resistance | Rosemont Eng. Co. 102CY2CG +414 L Bridge | -100 to +200°C | =±0.1°C (Manuf. Spec.) | =1 sec | Yes | 1.4W/28VDC | Modified to give 0-5V output |
| Static Air Temperature ($T_{STAT}$) | Platinum wire resistance | In House | -100 to +100°C | ±0.5°C | =1 sec | Yes | 6W/28VDC | Minco resistance element in reverse flow housing (S1083) Recovery coefficient) =0.2-0.3 Unreliable under icing conditions |
| Dewpoint | Dew condensation type | Cambridge Model 880 | -40 to +50°C | =+1°C (Manuf. Spec.) | 2°C/sec | Yes | 50W/115VAC | Modified to give 0-5V output for linear output over -40 to +10°C |
| Pressure Altitude | Absolute capacitance pressure | Rosemont Eng. Co. Model 830 BA | 0-15 psi | =±0.2% full scale (Manuf. Spec.) | No specs | Yes | 3W/28VDC | |
| True Air Speed (TAS) | Differential capacitance pressure sensor | Rosemont Eng. Co. Model 831 BA | 0-±1 psi | =±0.2% full scale (Manuf. Spec.) | No specs | Yes | 3W/28VDC | TAS derived by means of on-board in-house built analog computer |
| Air Turbulence | Differential pressure sensor Model 1120 | Meteorology Research Inc. | 0-10 $cm^{2/3}$ $sec^{-1}$ | =±10% | 3 sec | Yes | 20W/28VDC | |

TABLE A-1 (continued)

| Parameter | Instrument Type | Manufacturer and Model No. | Range | Error | Time Constant | On-Board Recorded? | Power Requirements | Remarks |
|---|---|---|---|---|---|---|---|---|
| Liquid Water | Hot wire resistance | Johnson Williams | 0-2 gm $m^{-3}$ 0-6 gm $m^{-3}$ | No specs | No specs | Yes | 110W/115V/400Hz 420W/28VDC | |
| Electric Field in Vertical Plane | Rotary field mill | Meteorology Research Inc. Model 611 | 0-±100kV $m^{-1}$ | ±10% | 0.2 sec | Yes | 20W/115V/400Hz 120W/28VDC | Modified for 0-5V output and calibration circuitry added for ±20kV $m^{-1}$ |
| Hydrometeor Sampler | Metal foil impactor | Meteorology Research Inc. Model 1220A | Particles greater than 250 μm in size | | | | 300W/28VDC | |
| Cloud Particle Sampler | Continuous particle replicator | Meteorology Research Inc. Model 1203D | | No specs | | Yes | 300W/28VDC | |
| Ice Crystal Counter | Optical polarization technique | In house | 0-1000 particles per liter | No specs | Immediate | Yes | 180W/28VDC 50W/115V 160Hz | 50 μm diameter minimum detected crystal size |
| Cloud Condensation Nuclei | Optical counting by light scattering | In house | 0-5,000 cloud condensation nuclei/$cm^3$ | ±10% | 1 Cycle per 15 sec | Yes | 500W(Max)/115V/ 60Hz | |

TABLE A-1 (continued)

| Parameter | Instrument Type | Manufacturer and Model No. | Range | Error | Time Constant | On-Board Recorded? | Power Requirements | Remarks |
|---|---|---|---|---|---|---|---|---|
| Ice Nucleus Concentrations | NCAR acoustical counter | E. Bollay Assoc. (modified in house) | 0.01-500 counts per liter | No specs | 20 sec rise time several minutes delay | Yes | 250W/115V/60Hz | Modified humidity control and aerosol generator. Compressor converted to 28VDC |
| Ice Nucleus Concentrations | Fast response polarizing technique | Mee Indust. | 0.1-10000 counts per liter | No specs | 10 sec | Yes | 175W/28VDC | |
| Sodium Particle Counter | Flame spectrometer | In house | 0-10,000 per liter | ±1% | Immediate response | Yes | 60W/115V/60Hz | Detects NaCl particles larger than 0.05 μm in diameter |
| Altitude above Terrain | Radar altimeter | AN/APN22 | 0-20,000 ft. | ±5% of indicated value | No specs | Yes | 36W/28VDC 120W/115V/400Hz | |
| Weather Radar | 5 cm gyro stabilized | Radio Corp. America AVQ-10 | 50 nautical miles | No specs | | No | | Addition monitor at position U |
| Aircraft Position and Course Plotter | Works off DME and VOR | In house | 80 miles | ≈1 mile | 10 sec | Yes | 30W/28VDC | Gives real time plot on sectional map of area of position of aircraft |
| Time | Time code generator | Systron Donner Model 8220 | hrs, min, sec, (IRIG B code) | 1 part in $10^5$ | | Yes | 12W/115V/60Hz | Modified for 28VDC operation. Hr, min, sec, display |

TABLE A-1(continued)

| Parameter | Instrument Type | Manufacturer and Model No. | Range | Error | Time Constant | On-Board Recorded? | Power Requirements | Requirements |
|---|---|---|---|---|---|---|---|---|
| Time | Radio WWV | Gertsch RHF 1 | min | | | Yes | 1W/28VDC | 2.5, 5, 10, 15 mHz Voice announcements are recorded on tape |
| Ground Communication | FM transceiver | Motorola | approx. 100 miles | | | No | Internal batteries | 150 MHz band |
| Integrating Nephelometer | Optical Light Scattering | Meteorology Research, Inc. Model 1567 | 0 to 2.5 $\times 10^{-4}$<br>0 to 10 $\times 10^{-4}$ | ±10% | 10 sec | Yes | 200W/115V/60Hz | |
| Dew Point | Dew condensation type | Cambridge Systems Model TM73-244 | -40°C to +40°C | ±1°C | 2°C/sec | Yes | 55W/115VAC/ 400Hz | Switch selectable ranges for -40° to +10°C and -10° to +40°C |
| Heading | Gyro-compass | Sperry Model C-2 | 0-360° | ±2° | 200°/sec | Yes | 100W/115VAC/ 400Hz | Slaved to navigation compass through synero-Digital converter |
| Ground Speed and Drift Angle | Doppler Navigator | Bendix Model DRA-12 | 0-20,000 ft. | No specs | No specs | Yes | 200W/115VAC/ 400Hz | Basic sensor for computing horizontal wind direction and velocity. |
| Ultra-violet Radiation | Barrier-layer photo-electric cell | Eppley Laboratory, Inc. #14042 | 0-100 mcal-cm$^{-2}$ min$^{-1}$ | 5% full scale | 0.1 sec | Yes | 1W/28V | |

TABLE A-1(continued)

| Parameter | Instrument Type | Manufacturer and Model No. | Range | Error | Time Constant | On-Board Recorded? | Power Requirements | Remarks |
|---|---|---|---|---|---|---|---|---|
| Angle of Attack | Potentiometer | Rosemount 861 | ±23° | ±0.5° | 0.1 sec | Yes | 1W/28V | |
| Photographs | 35-mm time-lapse camera | Automax Model GS-2D-111 | -- | -- | 1 sec to 10 min | -- | 75W/28V | Automatic recording of time of day, flight number and aircraft heading on each frame. |
| Total Gaseous Sulfur | FPD flame photometric detector | Meloy 285 | 0-1 ppm | ±10 ppb | 0, 1, 10 sec | Yes | 200W/115V/60Hz | |
| Ozone | Chemiluminescence ($C_2H_4$) | Monitor Labs 8410'A | 0-5 ppm | ±7 ppb | ≥ 1 sec dependent on range | Yes | 250W/115V/60Hz | |
| NO, $NO_2$, $NO_x$ | Chemiluminescence ($O_3$) | Monitor Labs 8440 | 0-5 ppm | ±7 ppb | ≥ 1 sec dependent on range | Yes | 200W/115V/60Hz | |
| Aerosol Particles | Mobility analysis | TSI 3030 | $1.3\times10^{-2}$-$4.2\times10^{-1}$ μm | $\frac{1}{\sqrt{N}}$ * | 120 sec | Yes | 20W/117V/60Hz | |
| Aerosol Particles | 90° light scattering | ROYCO 202 (modified) | 0.3-10μm | $\frac{1}{\sqrt{N}}$ | 6 sec | Yes | 20W/117V/60Hz | |

* N = number of measurements

TABLE A-1(continued)

| Parameter | Instrument Type | Manufacturer and Model No. | Range | Error | Time Constant | On-Board Recorded? | Power Requirements | Remarks |
|---|---|---|---|---|---|---|---|---|
| Aerosol Particles | Forward light-scattering | Royco 225 (modified) | 1.7-39μm | $\frac{1}{\sqrt{N}}$ | 6 sec† | Yes | 40W/117V/60 Hz | |
| Aerosol Particles and Cloud Particles | Forward light-scattering | PMS ASSP100 | 2.8-66μm | $\frac{1}{\sqrt{N}}$ | 6 sec† | Yes | 60W/117V/60 Hz<br>100W/28V DC | |
| Cloud Particles | Diode occultation | PMS OAP-200X | 20-300μm | $\frac{1}{\sqrt{N}}$ | 6 sec† | Yes | 60W/117V/400 Hz<br>100W/28V DC | |
| Precipitation Particles | Diode occultation | PMS OAP-200Y | 300-4500 μm | $\frac{1}{\sqrt{N}}$ | 6 sec† | Yes | 60W/117V/400 Hz<br>100W/28V DC | |
| Aitken Nuclei | Light transmission | General Electric CNCII (modified) | >0.002μm | $\frac{1}{\sqrt{N}}$ | 1.5 sec | Yes | 200/117V/60 Hz | |
| Aerosol Particles | Direct impaction | Glass slides | 5-100μm | | | | | |
| Ice Nuclei | Filtration | Nucleopore/ Millipore | 0.2-200μm | | | | 150W/28V DC | |
| Aerosol Particles Mass | Electro-static deposition | TSI Model 3021 | 0.2-2μm | | 120 sec | Yes | 100W/117V/60 Hz | |
| Aitken Nuclei | Rapid expansion chamber | Gardner Type CN | 0-2 x $10^5$/CN < 0.002μm | $\frac{1}{\sqrt{N}}$ | | | | |

†Limited by method of recording